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Automation of assembly processes

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Abstract
Large-scale manufacturing companies use larger automated assembly processes including the use of heavy robotic equipment to put together large products, such as automobiles. The assembly lines in these systems have centralized control, operated by only a few workers. However, the lines, as production elements, are independent in the assembly process. Automated assembly systems are designed to perform assembly operations in a fixed manner product assembly sequence. Four types of systems/operational planning problems are significant: delivery of parts to workstations; single station system; automatic multi-station systems; and partly automation. This paper focuses on the multi-station automated system used for operational assembly.

Keywords
automated assembly systems, Industry 4.0, performance analysis

1. Introduction to Automated Assembly Systems

Technology has made major advances for almost every industry. Manufacturing is one of those industries. The assembly process is an area that has seen significant changes. Automation from these technological advances has been key to business operation and efficiency for many years [1].

In many factories today, automated assembly is used to create parts and then assemble a wide variety of consumer goods, from food to electronics. Large-scale manufacturing companies use larger automated assembly processes, including the use of heavy robotic equipment to assemble large products such as automobiles.

Automated assembly refers to a way of producing goods using automatic assembly machines or robots, and a systematic approach to assembling goods that operates at least partially independently of human control. In most cases, automated machines are used to produce products using standardized parts added in a specific series of movements or activities along what is commonly called an assembly line.

Assembly involves the joining together of two or more separate parts to form new entity which may be assembly or subassembly. Automated assembly refers to the use of mechanized and automated devices to perform the various functions in an assembly line or cell [2].

Automated assembly is defined as the use of means of mechanization and automation to perform at least some production functions on assembly lines and cells. Robotics is the main means behind the great advances in assembly processes. Industrial robots have become direct productive (processing) and auxiliary (servicing, handling, etc.) components in assembly systems. With all the established advances, assembly is a particular field of automation [2, 3].

Automated assembly system performs a sequence of automated operations to combine multiple components into a single entity which can be a final product or sub assembly.

Automated assembly technology should be considered when the following condition exists:

- High product demand;
- Stable product design;
- The assembly consists of no more than a limited number of components;
- The product is designed for automated assembly.

1.1. Designs for automated assembly

When designing a product to be assembled automatically, the following principles must be considered [4]:

• *Reduce the amount of assembly required*: This principle can be realized during design by combining functions within the same part that were previously accomplished by separate components in the product. The use of plastic moulded parts to substitute for sheet metal parts is an example of this principle. A more complex geometry moulded into a plastic part might replace several metal parts. Although the plastic part may seem to be more costly, the savings-in assembly time probably justify the substitution in many cases.

• *The use of modular construction*. In automatic assembly, the increase in the number of assembly phases/operations performed on a single automatic system will lead to an increase in the number of refusals in operation and therefore in the number of system blockages. One of the ways to reduce the number of blockages is the use of components in modular construction in the assembly of products, which helps both to specialize in the manufacture of products and in their servicing. It is recommended that a module is composed of a maximum of 12⋯14 components.

• *Reducing the number of fixings (tightening) imposed in the assembly process*. Instead of individual threaded and similar fastenings, it is recommended to use simultaneous tightening in several points with clips, clamps, and other elements for fast, simultaneous tightening of several components on the base.

• *Elimination of the simultaneous handling of several components*. One of the particularities of assembly processes consists in dividing them into simple operations, executable individually and successively in different stations. Concentrating these operations in a single job involves handling several components and executing all these operations in that job. The automation of such actions implies the strict and rapid ordering of these activities, which becomes possible only by robotizing the assembly process in that post.

• *High component quality constraints*. A high-performance automatic assembly requires components executed in compliance with the conditions of geometric, dimensional and positional precision that enter the process. Failure to comply with the conditions mentioned when processing the components leads to numerous dysfunctions on the assembly flow, caused by numerous long-term blockages.

• T*he use of storage units with current reserve per flow*. On the assembly flow, storage units with a current reserve of components must be provided to eliminate asynchronies and blockages.

1.2. The advantages and disadvantages of automatic assembly

One of today's controversial issues in the field of automation is the estimation of advantages and disadvantages of automation applications in manufacturing systems [5, 6]. The specialized literature lists the main advantages and disadvantages of automating the assembly process (Table 1).

Table 1. The advantages and disadvantages of automatic assembly

The advantages	• Difficult and labor-intensive activities like moving heavy or even very tiny objects that are beyond the human abilities have been conducted by automated systems • Labor activities in a dangerous environment such as those with extremely high temperature or toxicity and radiation are easily conducted by automated systems • Products that are required to be made with the very quick or slow speed that is beyond human capability are produced easier • Production speed increases while total cost per product drops due to less labor cost per product • Accuracy and precision of the automation system thanks to the incorporation of quality control systems is higher which results in high quality and uniform products with less defect • Automation systems never become tired or bored and they do not call in sick • Enabling the production of multiple shifts and weekends • More free time for workers to do other tasks

	• Increases the number of higher-level jobs in the automation production, maintenance, and running of the automated processes • The flexibility of manufacturing processes to switch from one product to the other one without the need to build a new production line
The disadvantages	• There are still many processes such as assembly of products with inconsistent component sizes that are not possible to be automated • Automation is usually effective for repeated, consistent and large volume products otherwise expenses of automation would be more than manual processes • Initial costs to run an automated manufacturing system is quite high since it requires advanced machinery, hardware, and components • Increase of stress and reduction of relaxing tasks • The maintenance department is demanded for any services and maintenance of the automation system in case of breakdowns or stops • Production loss in case of failures and breakdowns of the system • Accurate estimation of automating cost in a company is quite difficult which may impact on wrong profitability calculation and lead to no economic advantage of process automation • Engineering and product design challenges to have the capability of production by present automated systems • Social effects which lead to change the nature of the work from manual to automated that makes many workers jobless or displacement

2. Analysis of Automatic Assembly Systems

2.1. Analysis of a single station assembly machine

In the single-station assembly machine, the assembly operations are performed at a single location (stationary base part system). The typical operation involves the placement of the base part at the workstation where various components are added to the base, Figure 1. The components are delivered to the station by feeding mechanisms, and one or more work heads perform the various assembly and fastening operations.

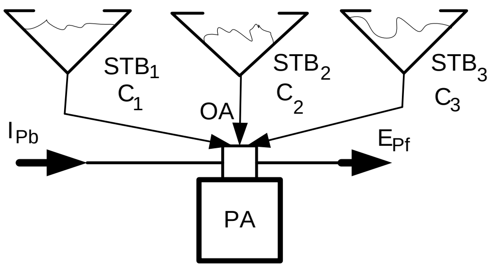


Fig. 1. Automatic assembly in an assembly station

In a single assembly station PA, three components $C_k \in \{C_1, C_2, C_3\}$ are assembled on a base piece P_b. The components enter the assembly area by automatic feeding from three hoppers STBk, k = 1, 2, 3, each feeding the assembly area with one component, and the base piece is automatically introduced into the work area, through a feeding system on the I_{Pb} input of the assembly station. Assembling each component requires an assembly time t_{Aek}, corresponding to each component $C_k \rightarrow S_{Aek}$, k = 1, 2, 3.

The duration of the assembly cycle will be equal to the sum of the elementary times of serial assembly, plus the handling times of the components and the assembled product, i.e.:

$$T_A = \sum_{k=1}^{3} t_{Aek} + \sum_{k=1}^{3} \left(\sum_{i=1}^{n_{man\,k}} t_{man\,i} \right)_k \qquad (1)$$

In each hopper there are an unpredictable number of components from each component C_k with defect, with probability (p_{ck}), which produce jams in assembly station PA_i, with probability P_{Ai}. When a reject occurs in operation, the assembly machine stops and requires an average repair time $T_{b\,\text{med}}$ to remove the rejects during the cycle, so the duration of the assembly cycle is:

$$T_{rA} = T_A + \sum_{b=1}^{n_b} (p_c \times p_A \times \bar{t}_b)_b \tag{2}$$

$$\bar{T}_b = \sum_{b=1}^{n_b} (P_c \times P_A \times \bar{t}_b)_b \tag{3}$$

$$T_{rA} = T_A + T_{b\,\text{med}} \tag{4}$$

The efficiency of the assembly station will be:

$$E_A = \frac{T_A}{T_{rA}} \quad [\%] \tag{5}$$

2.2. Analysis of a multi station assembly line

It is considered an automatic multi-station assembly system, machine or line, with a synchronous transfer system, Figure 2. The main performance indicators used in automatic assembly evaluations are productivity, efficiency and production costs.

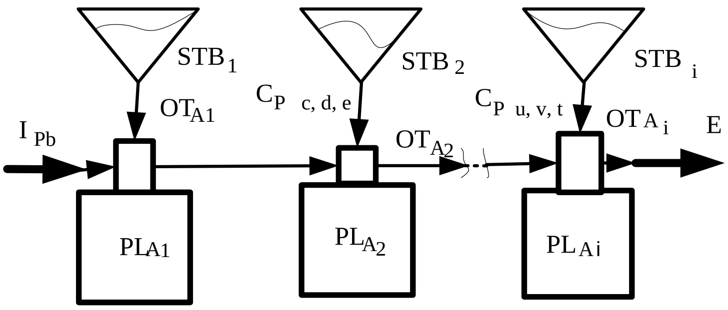


Fig. 2. Multi-station automatic assembly system

The analysis of multi-station assembly systems is similar to the transfer lines for mechanical processing, the evaluation being done for long blockages (at the upper limit). The systemic differences are that while in a processing system, in a predictable time interval, a single benchmark (R_k, k = ct), programmed predictably and definitely, enters and leaves, in an assembly system, in the same predictable time interval, several components enter (R_k, k = var) and a single finished product programmed in time, probabilistically (unpredictable and uncertain), comes out, representing the combination of components in a single aggregate product.

Figure 2 shows the composition and configuration of a multi-station assembly system in which PL_{Ai} is the current assembly workstation and where the current assembly operation is performed OT_{Ai}, STB – the hopper type storage, P_b – the base part, $C_{P\ a,b,\ ,c,\cdots,t,u,v}$ – the components that are assembled on the base part in the various assembly stations. On input I of the assembly system, the basic part/marker P_b is inserted. In each successive PL_{Ai}, to the intermediate subassembly obtained in the previous $PL_{A(i-1)}$, one or more C_P components a, b, c,⋯, t, u, v, extracted from the STB_i hopper storage, are added. After passing the base part through all the serial assembly stations, in which all the components a, b, c,⋯, t, u, v were added, the finished product P_f, fully assembled, is obtained on the exit E.

If all the constraints are not met in a station, the respective station is blocked by refusals in operation, caused by breakdowns, stiffening, gripping, breaking, deformations, etc. They produce blocking of the entire machine or line, in rigid construction. As a result, unlocking the faulty PL_{Ai} by repairing it causes the entire system to shut down. The peculiarities of assembly system blockages consist in the fact that they are divided into two large classes, namely: blockages of component subsystems of the assembly system and blockages produced by defective components that enter the assembly process, being harmful to the continuity and stability of the manufacturing flow.

3. Case Study

Next, the assembly process will be analysed for a product "Block with two contacts", for which the components are detailed in Table 2. Figure 3 schematically shows the sequence of assembly operations.

Table 2. Parts list

Assembly		Subassembly		Part	
Name	Qty	Name	Qty	Name	Qty
block contacts (B2C)	1	Contacts (C)	2	Blades (L)	4
				Spacer (D)	2
				Rivets (N)	4
		Plate (1)	1	Plate (P)	1
				Screws (S1+S2)	(2+1)
				Washers (R)	6
				Nut (Pi)	3
				Electrical conductors (CE)	3
				Bridge (b)	2

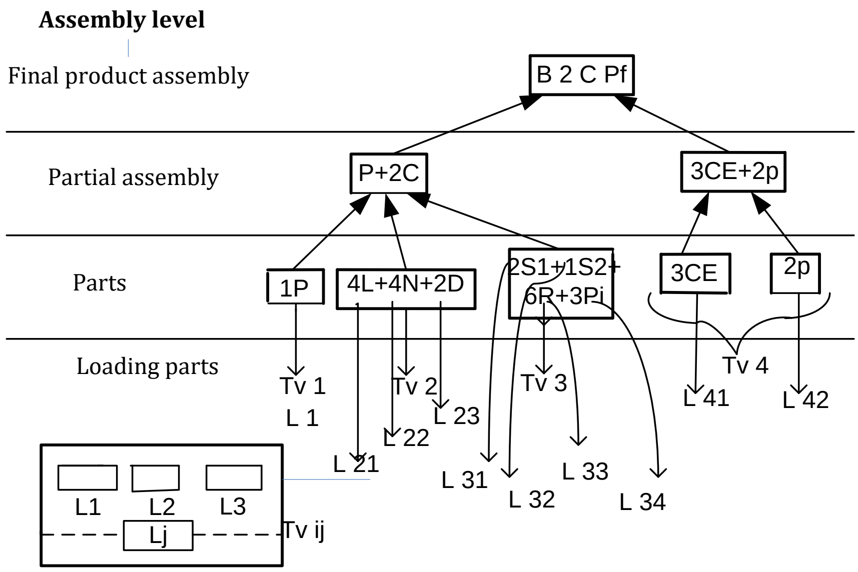


Fig. 3. Decomposition graph of the product

Next, the assembly process will be simulated in Tecnomatix plant simulation software (student version), knowing the assembly times for each workstation. The summary technological sheet is presented in Table 3.

The layout of the assembly line is schematically represented in Figure 4. The automatic assembly line is composed of five workstations, conveyors and two manipulator robots, with the role of loading and unloading parts.

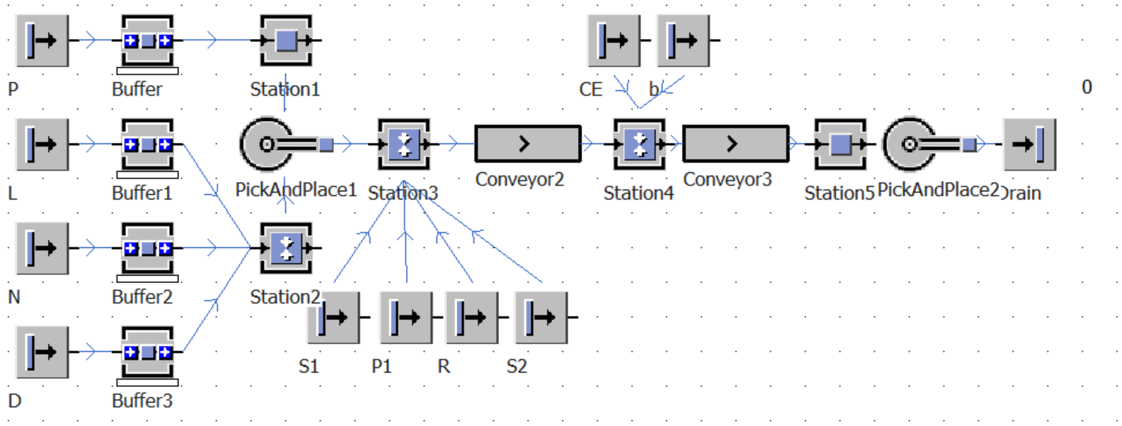


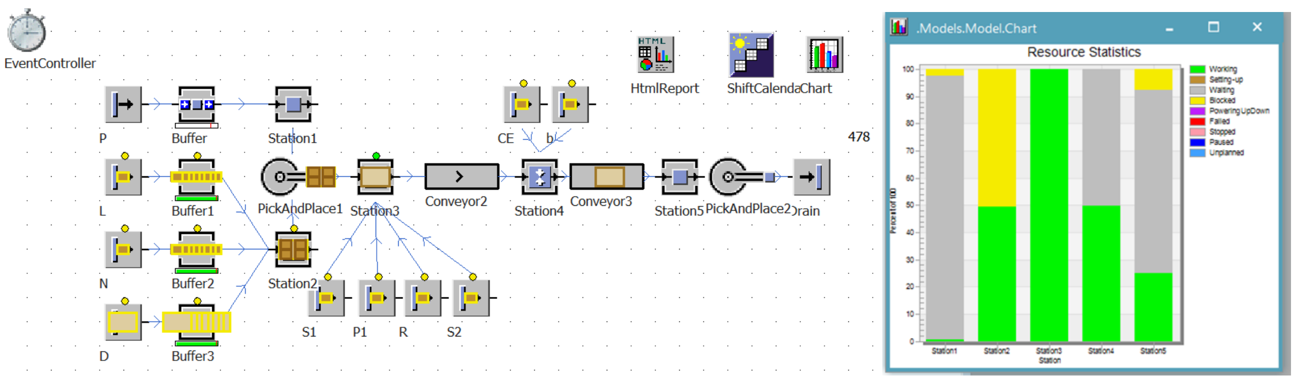
Fig. 4. Assembly line layout

The simulation was carried out for a determined duration of time, equal to the duration of an 8-hour work shift. The simulation did not include technical (failures of workstations or handling equipment) or organizational (for example, missing components) disturbances that would lead to blocking the line and stopping it.

The simulation in Tecnomatix helps to establish the optimal parameters for the conveyors, such as the speed of movement and the length of the conveyor belt, as well as the parameters of the manipulator robot, such as the loading/unloading time.

Simulation is essential software tool that improve design and planning of complex automated manufacturing and assembly systems. Systems with high level of complexity need to be tested even before they are constructed in real manufacturing plant. Elimination of errors in production before the first test production is initiated means huge savings in expenses and time [7].

The simulation results (Figure 5) show us the degree of load for each workstation (green color), but also the fact that the workstations have a waiting time (grey color), with the workstation empty or a time during which they are waiting to transfer the part of the next workstation (yellow color). During an 8-hour shift, 478 products can be assembled, which means that the assembly line has a tact of 0.99 pieces/min.



Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Station1	0.56%	0.00%	97.20%	2.25%	0.00%	0.00%	0.00%	0.00%	0.00%	
Station2	49.38%	0.00%	0.00%	50.63%	0.00%	0.00%	0.00%	0.00%	0.00%	
Station3	99.91%	0.00%	0.09%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Station4	49.90%	0.00%	50.10%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Station5	24.90%	0.00%	67.64%	7.47%	0.00%	0.00%	0.00%	0.00%	0.00%	

Fig. 5. Automated assembly line simulation results

5. Conclusion

The benefits of production line automation include increased capacity, increased quality, and lower unit production costs, allowing companies to realize a higher return on investment. Automation solutions work with limited staff, reduce errors, and waste, and increase productivity, reducing the unit cost of the product and applying more money to the bottom line. Automated assembly systems are designed to perform assembly operations in a fixed manner product assembly sequence. Four types of system/operational planning problems are significant: delivery of parts to workstations; single station system; automatic multi-station systems; and partly automation. This paper focuses on the multi-station automated system which is used for operational performing assembly operations. The main advantages of assembly simulation are to shorten development times, to eliminate design errors in assemblies before putting them into operation, to test several versions of assembly systems or workstations. An example simulation of the assembly system was done in the Tecnomatix.

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